Non-Demolition Adiabatic Measurement of the Phase Qubit State

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An adiabatic method for a single-shot non-demolition measurement of the phase qubit is suggested [1]. The qubit is inductively coupled to a low-frequency resonator, which in turn is connected with a classical measurement device (phase meter). The resonator drives adiabatic oscillations of the supercurrent in the qubit loop. The back reaction of the qubit loop on the resonator depends on the qubit state. By measuring the phase shift of the resonator's oscillations one can determine the state of the qubit. Numerical computations with available experimental parameters show that the phase difference between the two qubit states increases at a rate of 0.0044 rad/ns with a fidelity of about 0.9989 and a measurement time of about 100 ns. The fidelity of the measurement is estimated by taking into consideration possible quantum transitions inside and outside of the qubit manifold. An increase of the phase difference is possible, but it is linked to a reduction of the fidelity. The requirements for the reproducibility of the qubit and resonator parameters are formulated.

The idea of our approach is the following. We assume that the "qubit loop" (QL) is inductively coupled to the superconducting low-frequency measurement resonator (MR). There is an "adiabatic switch" that allows one to "turn on" or "turn off" the QL-MR coupling adiabatically with respect to the QL and "instantaneously" with respect to the MR. The adiabatic switch can be implemented by a variable mutual inductance, which is already developed. In this design, a current bias applied to a direct current superconducting quantum interference device (DC SQUID) controls the screening current, which influences the inductive coupling between two circuits.

The scheme of our design is shown in Fig. 1. The supercurrent in the MR oscillates with a much lower frequency than the frequency of the phase qubit. The MR oscillations cause oscillations of the flux in the QL. As a result, the positions of the minima of the potential energy of the qubit adiabatically oscillate. Thus, the supercurrent in the QL adiabatically oscillates with the frequency of the MR. The back action of the QL oscillations on the MR causes a phase shift in the MR oscillations. This phase shift depends on the qubit state. By measuring the phase shift of the MR oscillations one can determine the state of the phase qubit. Note that the qubit, which is placed initially in one of its basis computational states (ground or excited), remains in the same state during the measurement. If the qubit is placed initially into a superposition of the two basis states, it is expected to collapse quickly to one of its basis states. This should happen because the z-component of the phase qubit Bloch vector is an adiabatic invariant of the QL-MR dynamics, which does not change in the process of the phase measurement. Thus, our scheme describes a non-demolition projective measurement of the phase qubit. Note that the interaction between the QL and MR in our scheme is supposed to be strong enough so that the MR phase shift is not negligible in spite of the large difference between the qubit and MR frequencies. The low frequency oscillations in the resonator are supposed to be amplified with a microstrip SQUID amplifier (MSA) developed at LLNL, with almost quantum-limited noise. The phase of the amplified oscillations is measured with a phase meter.

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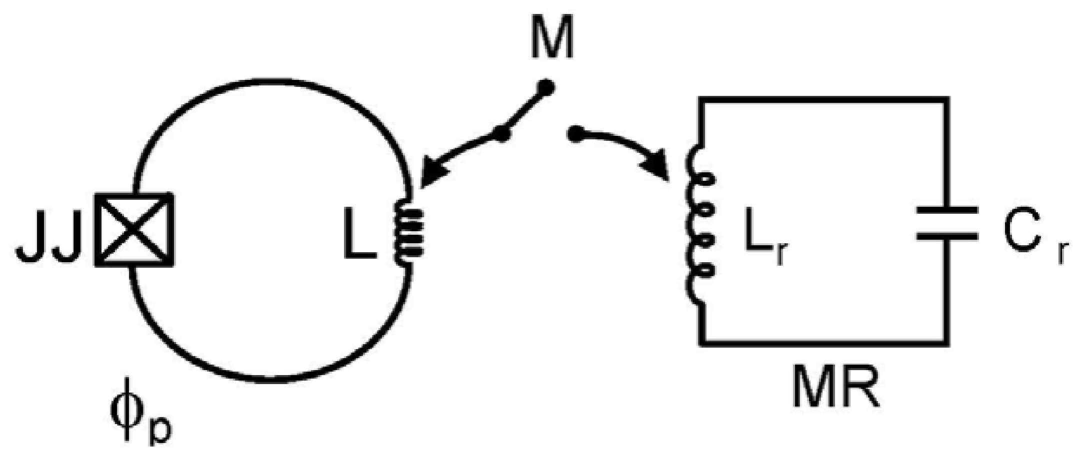
Fig. 1. The measurement scheme suggested in our work. The superconducting loop interrupted by the Josephson junction (JJ) is coupled inductively to a low-frequency measurement resonator (MR). M is the controllable mutual inductance, which can be turned on; ϕ_p is the external permanent flux which biases the QL; L_p and C_r are, respectively, the inductance and the capacitance of the MR; L is the QL inductance.



[1] Berman, G.P. et al., *Quant Inform Comput* **11,** 1045 (2011).

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